Handheld Microwave Radiometer for Education and Outreach

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Abstract — **This investigation features a low-cost (<$100) 1.413-GHz handheld microwave radiometer for use in educating students about microwave radiometry. The microwave radiometer presented is a conventional Dicke radiometer, but fabricated on low-cost printed-circuit board (PCB) material using inexpensive commercial off-the-shelf (COTS) parts. The instrument antenna is a rectangular horn fed by a stacked-patch probe-fed element. With a total weight of just about 2 kg (4 lbs) and a targeted overall cost of under US$100, the handheld radiometer presents several educational potentials in Earth and Sun science applications: primarily as a handy scientific tool for surface soil moisture measurements, and secondarily as a miniature solar radio telescope.**

I – INTRODUCTION

Passive microwave remote sensing is perhaps the least understood, yet a very important, technique used in Earth remote sensing. For example, microwave radiometers are used to sense atmospheric gases, clouds and precipitation; ocean surface temperature, winds, and salinity; and surface soil moisture. These state variables are used to drive numerical weather prediction and global circulation models. The public's exposure to remote sensing is often through the output of such models.

Even though recent studies have found that engaging students early in research project has proven to be an effective means of stimulating continued interest in scientific research [1], information about remote sensing instrumentation and techniques remain inaccessible to many higher-educational institutions due to the high cost of instrumentation and the current general inaccessibility of the science. In an effort to draw more talent within the field, early exposure of students to remote sensing applications is desired.

In this paper, we present a low-cost (<$100) 1.413-GHz handheld microwave radiometer for use in educating students about microwave radiometry. L-Band remote sensing at 1.413 GHz presents great value for environment applications including sea surface salinity and soil moisture mapping [2-3]. The radiometer can be used to teach relevant physical, engineering, and scientific principles. Several outlets for using the radiometer are possible. First, a soil moisture measurement protocol is being developed for the Global Learning Observations for a Better Environment (GLOBE) program – a worldwide program aiming to promote an awareness of the environment from a scientific viewpoint to students of early age. In addition, the instrument can serve as a student-operated validation tool to two pending NASA missions: Hydros and Aquarius. The microwave radiometer we have developed (see Fig. 1) is a conventional Dicke radiometer, fabricated on low-cost PCB material using inexpensive COTS parts. The instrument antenna is a rectangular horn fed by a stacked-patch probe-fed element. With a total weight of just about 2 kg (4 lbs) and a targeted overall cost of under US$100, the handheld radiometer is an accessible and practical educational tool.

Fig 1. Photograph of one of the authors and a summer intern demonstrating the handheld radiometer

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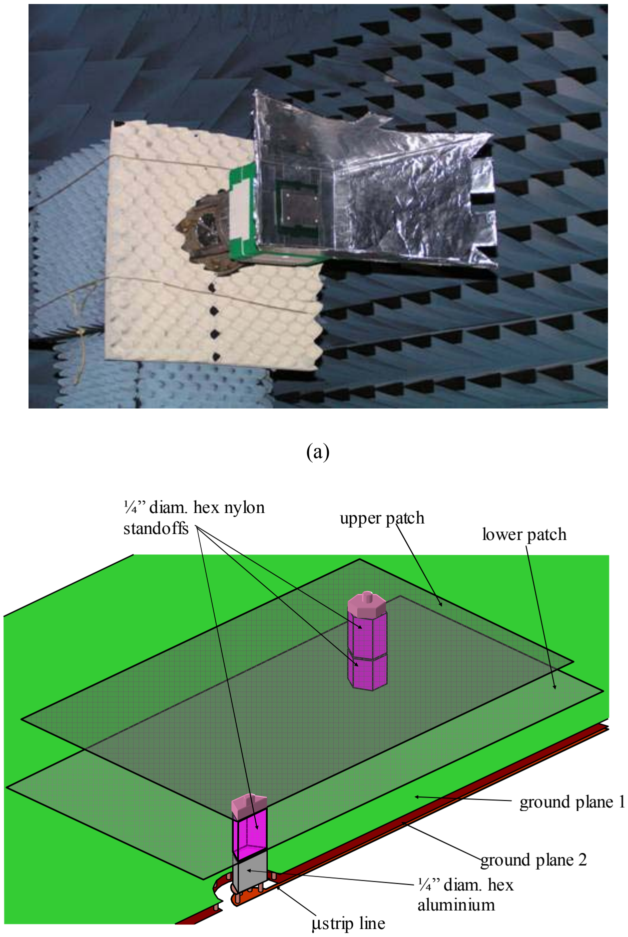
separated by a distance of 0.375’’ using nylon standoffs. The lower patch is 0.25’’ elevated from the PCB surface

Except for the PCB, all the materials needed to construct the antenna are readily available at local retail stores. To test the constructability of the antenna, the horn was constructed by a summer intern with no antenna engineering experience. Testing results of the feed antenna showed a return loss better than -20dB within the desired frequency range. Directivity measurements were performed at the Goddard Automated Antenna Measurement System (GAAMS). Results from these measurements showed close agreement with expected results.

B – RF Circuit

This receiver contained at its front-end a SPDT RF switch with adequate insertion loss of <1dB at 1.413GHz. The component is actuated by a TTL signal generated from a 555 timer at 50% duty cycle. An inexpensive monolithic LNA with a noise figure of 3.1 dB and high linearity over the RF bandwidth is used at the pre-amplification stage. The switch and LNA are located at the antenna probe to minimize insertion losses. This configuration lowers costs because no connectors are needed between the antenna and RF front-end.

Using a double-sideband, super-heterodyne Dicke architecture allowed us to use low-cost parts and avoid the use of high-cost parts. For example, we do not need an RF band-definition filter, which can cost several hundred dollars. Rather, we use the double-sideband receiver with a low-pass IF filter, costing only ten dollars. The amplifiers are plastic-packaged parts costing only ~US$1 each. Several stages of gain are used to amplify the signal to the desired detector input power level. The receiver along with the rest of the system is powered using a 9-volt alkaline battery. All components are shielded against radio-frequency interference (RFI) using on-board shielding enclosures. For all practical purposes, temperature regulation through cooling techniques [4] was considered but not adopted on ground because of expense. Figure 3 shows a five-channel version that was built in collaboration with Prof. Brad King and his students at the Michigan Tech University for the NASA/AFRL/AIAA Nanosat-3 Flight Competition in Jan. 2005.



(b)

Fig 2 (a). Handheld Radiometer antenna in anechoic chamber. The upper patch of the antenna is visible in the antenna horn cavity. (b) 3-D schematic of middle cross-section of antenna geometry. The metallic feed element connects to RF circuit (not shown) via a microstrip line

II – Design description

Among various considerations for the design were: size and weight, spatial resolution, ease of calibration, and most important cost. The design philosophy of the radiometer is to use a conventional, if not dated, architecture with low-cost parts. The instrument architecture consists of an antenna and the RF circuit.

A – Antenna

The antenna is one of the more innovative designs used in the handheld radiometer. The rectangular horn (or bucket) was made by covering a foam-core board frame with aluminum foil (see Fig.2a). The notched edges of the bucket walls are a quarter-wavelength in size and help reduce antenna back-lobes. The bucket is attached to the PCB assembly using aluminum tape. The feed configuration was carefully chosen to be insensitive to dielectric-constant variations and losses within FR4. The feed is a two-element stacked-patch antenna with a microstrip probe feed (Fig. 2b). The probe is the screw used to hold the assembly together. The two patches are

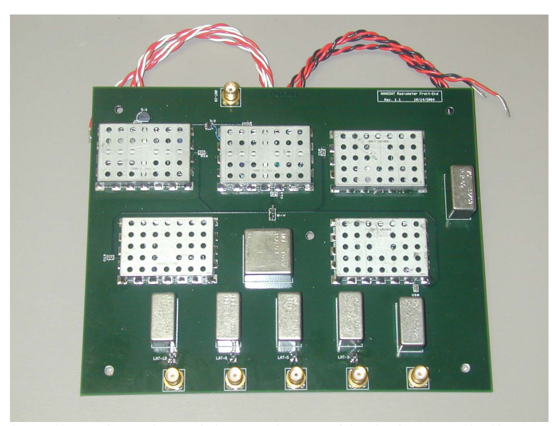


Fig 3. Five-channel version of the receiver. This design was built as a support to MichiganTech vehicle which placed third in the NASA/AFRL/AIAA Nanosat 3 Flight Competition in Jan. 2005

Not shown is the synchronous detector PCB, still under development. For our experiments, we used a laboratory lock-in amplifier for detector readout.

III – System calibration and experimental procedure

Although the handheld is designed to serve as an educational tool, to serve its purpose in GLOBE protocol as a "ground-truthing" and measuring instrument, its brightness temperature readings needs to be scientifically reliable. The protocol for calibration and soil moisture measurement is under development. However, we expect the procedure to include the following: 1) cold sky calibration, 2) accurate height and incidence angle measurements, 3) soil temperature measurement, and 4) periodic calibration against gravimetric moisture measurements.

A two-point calibration for total power radiometer similar to that described in [5] was carried out in the laboratory. The procedure consists of the application of a "hot" and "cold" load at the antenna. An absorbent material is dipped into liquid nitrogen (78 K) for the cold load. We use the internal Dicke reference for the hot load at the system ambient temperature (293 K). The receiver noise temperature was found to be ~1000 K.

Preliminary field experiments were conducted using an early version of the instrument. Experimental setting consisted of smooth soil with uniform vegetation – a tall fescue variety of grass. The experiment was repeated over the course of four days. Variations in radiometer output as a function of angle of incidence were observed and recorded. The instrument incidence angle was tracked using a digital protractor attached to antenna-horn. Fig. 4 show results for these measurements.

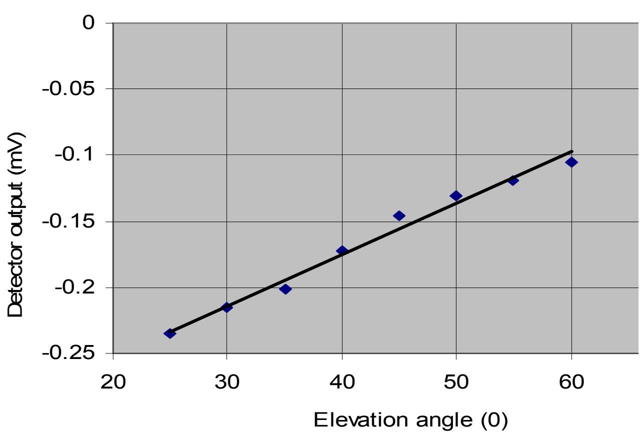


Fig.4. Radiometer output voltage amplitude as a function of antenna elevation or incidence angle. The antenna was oriented in vertical polarization. More negative voltages indicated lower brightness temperature, thus the output increases with angle.

A final experiment was carried out on a cloudy morning. The antenna was pointed at the ground, then at the sky to the west (away from the sun). We observed the radiometer output drop as the antenna was moved from the ground view to the sky view. Then the antenna was slowly pointed towards the east. As we approached the eastward view, the radiometer output increased greatly. The radiometer was receiving solar radiation through the clouds. This was an excellent demonstration of the ability of microwave radiometers to "see through clouds."

IV - Conclusion

We are developing an innovative low-cost handheld microwave radiometer for education and outreach purposes. The handheld is a Dicke radiometer designed for operation at the standard soil moisture applications frequency of 1.413GHz and will be powered using a 9-V battery. This instrument has a target cost of under US$100 and total weight around 2 kg. The instrument will benefit the remote sensing community by being a tool for educating students about passive microwave remote sensing.

IV – Acknowledgements

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